

THE USE OF DIC FOR HIGH STRAIN RATE MATERIAL TESTING

J. Peirs, P. Verleysen, W. Van Paepegem and J. Degrieck
Department of Materials Science and Engineering, University of Ghent
Sint-Pietersnieuwstraat 41, 9000 Gent, Belgium
Jan.Peirs@UGent.be Patricia.Verleysen@UGent.be

ABSTRACT: Digital Image Correlation (DIC) is used to study the local strain distribution in Ti6Al4V specimens during dynamic material tests. Three different test configurations are used: tensile and planar shear specimens loaded in a split Hopkinson tensile bar set-up and thin-walled tubular specimens loaded in a torsional Hopkinson set-up. For each experiment the optimal combination of frame rate and spatial resolution is determined. Additionally, for the torsion experiments, images of the tubular specimens are transformed prior to DIC to compensate for the curvature of the specimen surface. The results indicate that the local strain in the specimen differs significantly from the average strain. The full field strain measurement is recommended for material behaviour extraction.

1. INTRODUCTION

The split Hopkinson bar (SHB) technique is often used to characterize the high strain rate behaviour of materials in tension, compression and shear. In a SHB test a material sample is loaded by elastic waves propagating through slender bars. Strain gauge measurements on the bars yield the load and elongation history of the dynamically deforming specimen. The average stress and strain can usually be calculated quite accurately from the measured load and elongation. However, if no homogeneous strain distribution is obtained, the average strain differs significantly from the actual local strain in the specimen. This is the case for materials with low strain hardening such as Ti6Al4V and for complex specimen geometries. Therefore, measurement of the local strain is of high importance for correct interpretation of the experimental results. In this study, three different specimen geometries are used to characterize the dynamic behaviour of Ti6Al4V: a planar dogbone shaped specimen for tensile tests, a planar shear specimen [1] for shear tests and a thin-walled tubular specimen for torsion tests. The size of the deforming region of the three types of specimens is in the order of a few mm.

Because of the small specimen dimensions, the typically very short test duration and high plastic strains in dynamic experiments, local strain measurements are not evident. Although, non-contacting optical techniques such as digital image correlation are feasible, it is not without effort. Proper lighting of the small specimen, sufficiently high frame rate, shutter speed and image resolution are not obvious as for quasi-static strain measurements. However, DIC provides unique information about the strain distribution in the dynamic specimens. This knowledge is used for a better interpretation of the experimental results and for optimizing the specimen geometry.

2. EXPERIMENTAL SET-UP

2.1 High speed photography

In the dynamic tests, the specimen deforms to fracture in less than 0.5ms. A high speed camera is thus required to observe the specimen during the test. In this study, a Photron APX RS camera is used. The optimal frame rate, shutter speed, image resolution, lens aperture and focal length within the limitations of the equipment are studied. The optimum varies for different test configurations around a frame rate of 31500fps and resolution of 384x192 pixels. Depth of field is maximized by using a small lens aperture which is important for sharp images of the non-planar torsional specimens. A very high shutter speed is required to avoid motion blur and is therefore set on 2x the frame rate. Consequently, the quality of lighting is crucial to have good images and is strongly affected by the type and position of the light sources, especially because of the highly reflective Ti6Al4V surface. A fine speckle pattern is applied on the specimens for tracking of the deformation.

2.2 DIC

The non commercial software MatchID is used to calculate the strain field from the images (see acknowledgments). The Approximated Normalized Sum of Squared Differences (ANSSD) correlation algorithm is chosen because of accurate results and high performance [2]. Bicubic interpolation is used for the determination of the displacement field. The interpolation order is important for subpixel displacement accuracy which is required because of the not so high image resolution.

3. APPLICATION OF DIC

3.1 Planar tensile and shear test

Due to the low strain hardening of Ti6Al4V, necking of the tensile specimen occurs very soon. From this moment, the average and local strain deviate strongly. The strain in the central part of the specimen is more than twice the average strain. DIC enables to characterize the material behaviour up to high non-homogeneous distributed strains.

DIC provides also very useful information from the shear tests. Because the width of the shear region is not well defined, it is difficult to calculate the average strain from the total specimen elongation. With DIC it is possible to obtain the local strain and thus use the shear experiment for material behaviour characterization.

3.2 Torsion test

Due to the curved surface of the tubular torsion specimen, surface points have a 3D displacement field. In principle, two high speed cameras are necessary to calculate the strain field. However, one camera is sufficient when assuming that the displacement is confined on the cylindrical surface, which is the case for a pure-shear strain state. A routine in MatLab is made to correct the original images and thus taking into account the image distortion caused by the specimen curvature.

Figure 1 shows an example of the uncorrected (a) and corrected (b) speckle pattern on the surface of the torsional specimen. Only at the centre of the speckle pattern (position=0mm) the calculated displacement is the same for both images. The further away from the centre, the larger the difference.

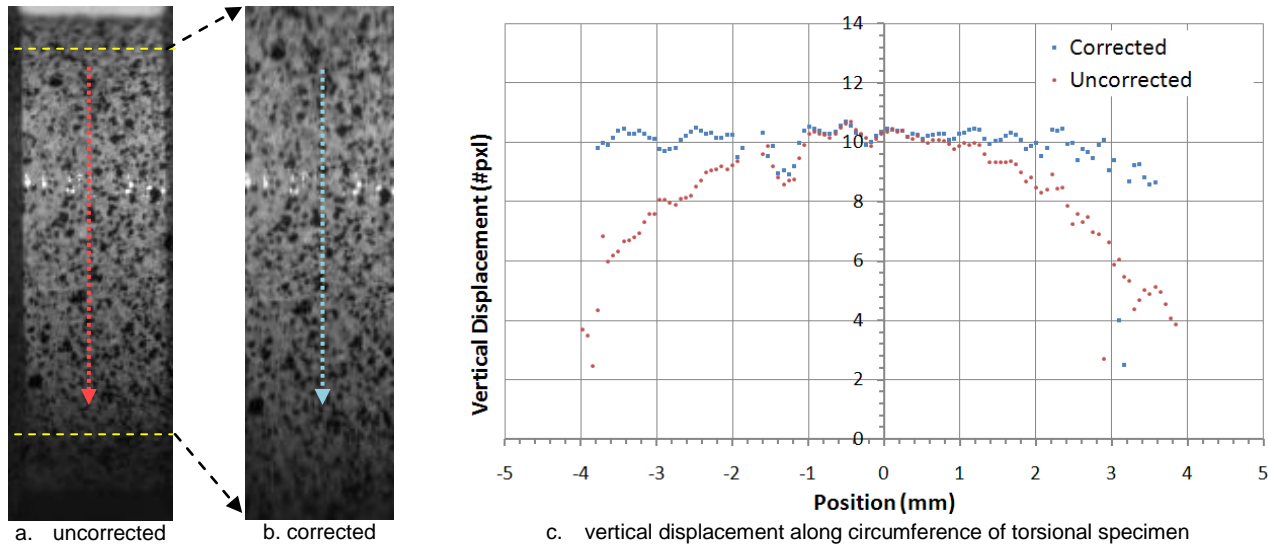


Figure 1: a. original and b. corrected image, c. vertical displacement along the circumference of a torsional specimen, measured with DIC on the uncorrected and corrected figures.

DIC of torsional specimens is further used to study the strain distribution in the axial direction. It is found that very minor variations in wall thickness of the specimen lead to important strain concentrations. These results are used for optimizing the specimen geometry for improved robustness.

4. CONCLUSIONS

Digital image correlation is applied on three different specimens for dynamic material characterization. First several practical problems which come from the short test duration and small specimens are tackled. Image distortion caused by the curved surface of torsional specimens is dealt with. Second, the strain distribution in the specimens is studied with DIC. It is found that DIC provides very valuable information, additional to the commonly obtained force and elongation history. The knowledge of the strain distribution is used for better interpretation of the experiments and for optimization of the specimen geometry.

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